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ANALYZING THE EFFECT OF NUMBER AND POWER FACTOR OF DG ON OPTIMAL ALLOCATION FOR MINIMAL POWER LOSS IN RDS

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Abstract: The integration of Distributed Generators (DG) into Radial Distribution Systems (RDS) has emerged as a promising solution for minimizing power losses and enhancing the voltage profile in power systems. This paper investigates the effect of varying the number and power factor of DG on its optimal allocation in RDS. The Grey Wolf Optimization (GWO) algorithm is used to propose an alternative optimization approach for the optimal allocation of DG in RDS. The Direct Load Flow method is utilized to analyze the power flow in the system. The study compares the appropriate DG allocation in IEEE 33 and 69 bus RDS under different DG parameters, including types of DG, problem statements, objective functions, constraints, load flow analysis, and simulation results. The results demonstrate that the optimal placement and sizing of DG can significantly reduce power losses and improve the voltage profile in RDS. The paper concludes that the use of renewable sources of energy like DG can enhance the performance of the radial system, but improper allocation can lead to adverse effects.

Keywords: Radial Distribution Systems, Distributed Generators, Grey Wolf Optimization, Direct Load Flow, Renewable Energy, Power Loss Minimization

1. Introduction

The depletion of fossil fuel deposits alongside the need to reduce greenhouse gas emissions has driven the integration of renewable energy sources like Distributed Generators (DG) into Radial Distribution Systems (RDS) for improved power quality. DG placement and sizing optimization is crucial to minimize power losses and enhance the voltage profile of RDS. Several optimization strategies have been proposed to achieve distribution system objectives, including analytical and heuristic methods. This paper investigates and compares the effect of variation in the number and power factor of DG on its optimal allocation in RDS using the Grey Wolf Optimization (GWO) algorithm. The Direct Load Flow method is used to handle power flow in the system. The study computes and compares the optimal DG allocation for IEEE 33 and 69 bus RDS under different DG parameters. The paper presents the types of DG, problem statements, objective functions, constraints, load flow analysis, and simulation results. Results show that the optimal placement and sizing of DG can significantly reduce power losses and improve the voltage profile in RDS. However, improper allocation can lead to adverse effects. The study concludes that the use of renewable sources of energy like

DG can boost the performance of the radial system, and the GWO algorithm presents an alternative optimization approach for the optimal allocation of DG in RDS.

2. Types of DG

Based on its terminal features in terms of real power (P) & reactive power (Q) providing capabilities, DG may be divided into

Type A: DG is solely capable of injecting P consisting of convertor/inverter-integrated photovoltaic, microturbine, and fuel cell power sources

$$S_{DGA} = \sqrt{(P_g + P_{DGA})^2 + (Q_g)^2} \quad (1)$$

Type B: DG is solely capable of injecting Q consisting of synchronous compensators, i.e., gas turbines.

$$S_{DGB} = \sqrt{(P_g)^2 + (Q_g + Q_{DGB})^2} \quad (2)$$

Type C: DG with the ability to infuse both P and Q mainly synchronous-machine-based DG units (cogeneration, gas turbine, etc.)

$$S_{DGC} = \sqrt{(P_g + P_{DGC})^2 + (Q_g + Q_{DGC})^2} \quad (3)$$

Type D: DG can infuse P but deplete Q comprising mainly of wind farm induction generators.

$$S_{DGD} = \sqrt{(P_g + P_{DGD})^2 + (Q_g - Q_{DGD})^2} \quad (4)$$

where P_{DGA}, P_{DGC} and P_{DGD} are the active power injected by DG & Q_{DGB} and Q_{DGC} are the reactive power injection whereas Q_{DGD} represents the reactive power demand by the DG.

3. Problem Statement

3.1 Objective Function: Minimize:

$$P_{loss} = \sum_{i=1}^{n} |I_i|^2 R_i \quad (5)$$

Constraints

Voltage constraint: To maintain the system's power quality, the voltage at each node must continue to operate within reasonable bounds.

$$V_{min} \le V_n \le V_{max} \quad (6)$$

where V_{min}& V_{max} are the lower and upper limits, V_n the voltage of n^{th} node and N the total nodes in the network. *Thermal Constraint:* The network's branch currents must all be well within the conductor's maximum thermal capacity.

$$I_m \le I_{rated} \quad (7)$$

where I_n and I_{rated} is the m^{th} branch and maximum allowable branch current respectively

DG capacity constraint: Every integrated DG unit's total active power generation must be less than the network's total active power consumption; otherwise, power would flow back.

$$0 \le \sum_{i=1}^{n} P_{DG_i} \le \sum_{i=1}^{n} P_{L_i} \quad (8)$$

where P_{DGi} the active power injection and P_{Li} the load connected to the i^{th} node.

3.2Load Flow Analysis: The distribution system is predominantly radial or weakly meshed with unbalanced loading due to the ever-changing load demand of various consumers, an immense number of nodes and branches, as well as resistance and reactance valuing large spans of the spectrum. The high R/X ratio causes high power losses in the system. Due to the above-stated features, traditional load-flow methods like Gauss-Seidel & Newton-Raphson fail to render the performance and robustness criteria and the assumptions of fast-decoupled NR method are invalid in distribution system. As a result, forward and backward sweep, as well as

DLF method, are the most common load-flow approaches adopted in the distribution network. In this work, DLF technique (Teng, 2003) has been used to perform the load-flow analysis saving profuse time and befitting for online application.

4. Grey Wolf Optimization

In 2014, SyedaliMirjalili et al.(Mirjalili et al., 2014), presented a novel population-based meta-heuristic optimization method called "Grey Wolf Optimizer" (GWO). The inspiration behind this algorithm is the hunting mechanism & social hierarchy of the Pack of grey wolves. The pack have stringent social dominant hierarchy where the alphas are leaders and primarily responsible for decision-making and are imposed on the pack. Although the alpha is not the strongest member of the pack, he is the greatest at controlling it. The betas, the best candidate for replacing alphas, are second to alphas assisting them in making decisions by reinforcing the alpha's order across the pack, as well as providing feedback to the alpha. The omegas are the lowest in the power pyramid and have to follow the rest and the remaining wolves are the deltas which submit to alpha and betas but dominate the omegas. Along with social hierarchy, wolves engage in collective hunting, which entails tracking, pursuing, surrounding, and eventually attacking exhausted victims.

Optimal placement of DGs: ***Input Data*****:** Bus Data ***Output:*** Optimal allocation Initialization:

1. DLF

Loop Process

2. Run GWO till Maxiter reached

3. Search agents—Randomly generated

Position of wolves—initialized

4. Objective Function-Calculate P_{loss} by calling DLF

5. If (P_{loss} violates constraints) — Discard Solution

6. else — Update position of wolves

7. If (Obtained position better than previous run) — Discard previous solution

8. else — Rerun GWO

4. Simulation Results

The differences in the characteristics that are compared among the two techniques taking GA as base case, as shown in Table 1 have a minute difference in values, but the average time taken for computation of the same set of values is considerable for a test case with a limited number of iterations and program runs. The authors observe that the computation time for GWO technique is much less compared to PSO & GA for the IEEE-33 bus test RDS with 600 iterations on a single run with comparable accuracy.

Table 1. Comparison of various Optimization.

Method	Results	Avg. Time
GA	2590.287 [6]	29.816 sec
PSO	2590.217 [6]	7.937 sec
GWO	2590.252 [6]	4.67 sec

4.1 Effect on Voltage Profile & Power Losses of IEEE 33 bus RDS

In the instance of IEEE 33 bus RDS, the total load drawn from the substation is 3715 kW and 2300 kVAR. According to the loadflow study done using DLF on the test system without installing DG, the total active power loss amounts to 210.98 kW while the total reactive power is 143.02 kVAR, with the minimum voltage being 0.90378 p.u at the bus no. 18.

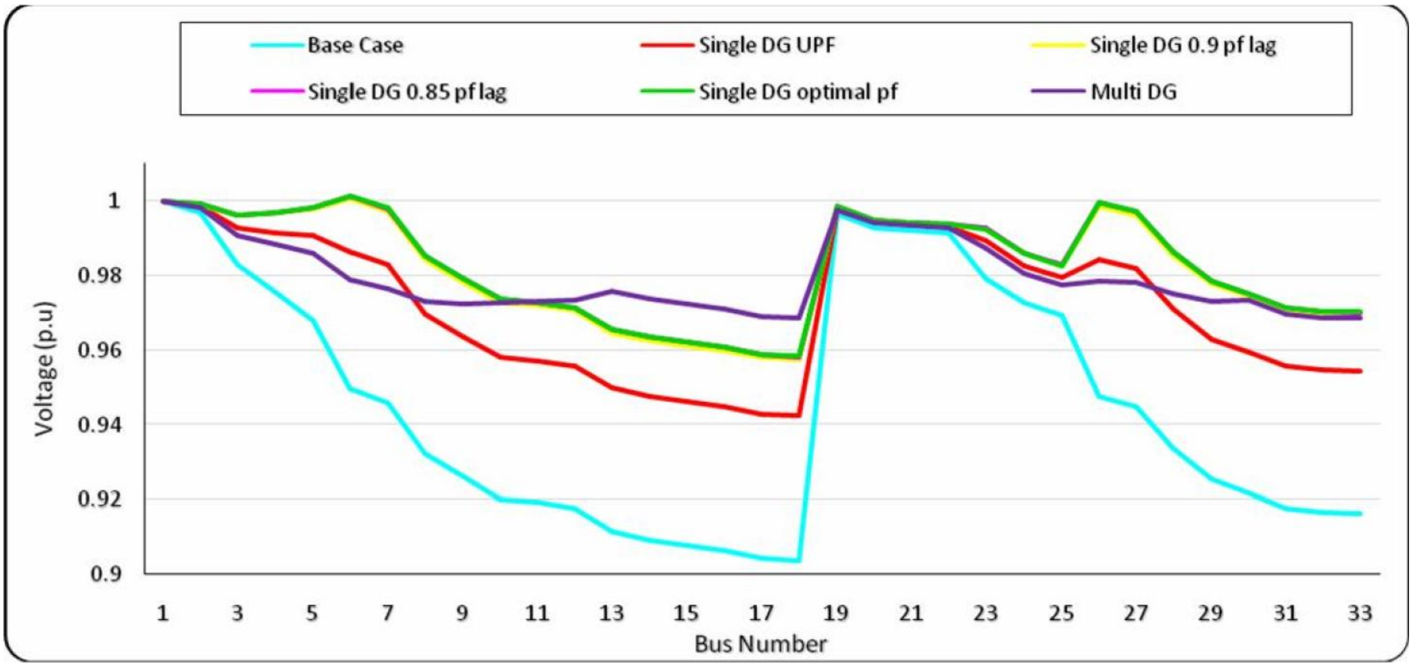
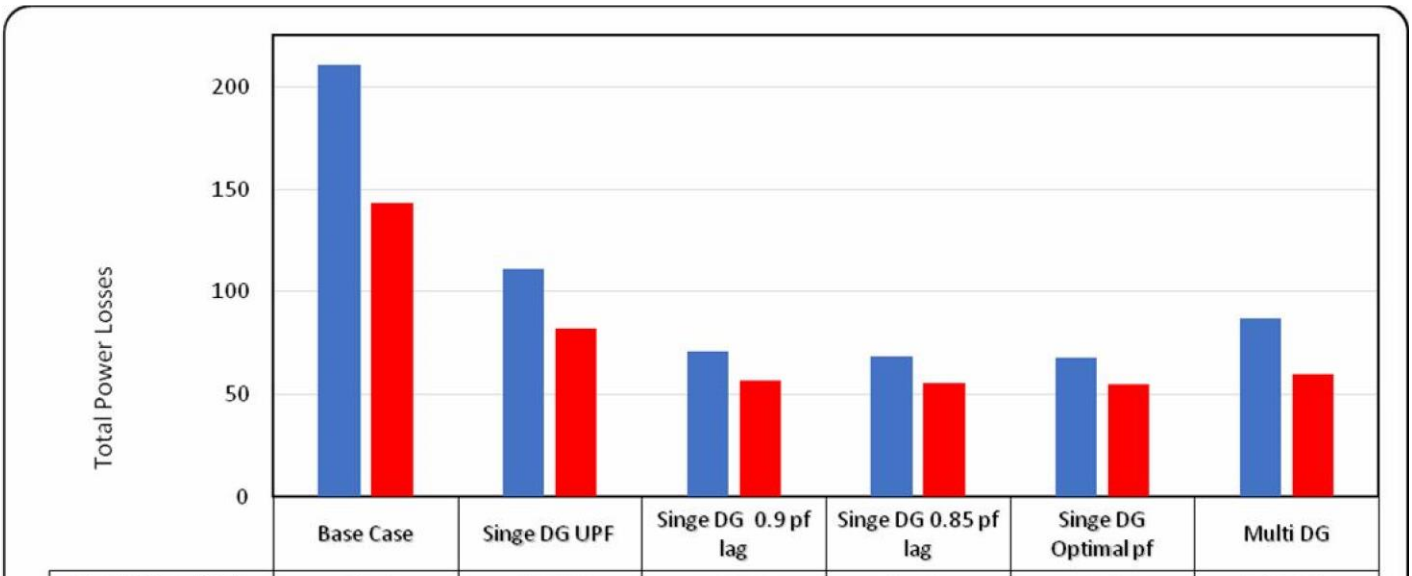


Figure 1. Variation of Voltage Profile in IEEE 33 bus RDS with implementation of various DGs.

Voltage Profile: Figure 1. represents the effect of the change in the number & power-factor of DG on the voltage profile, utilizing the aforementioned optimization approach and conducting the load flow analysis; the new voltage profile on the application of DG at the ideal position and the size determined shows the minimum value after DG implementation is more significant than the base case and keeps improving on increasing number of DGs and as the pf moves to its optimal value of 0.82378 pf lag.



	Base Case	Singe DG UPF	Singe DG 0.9 pf lag	Singe DG 0.85 pf lag	Singe DG Optimal pf	Multi DG
Total P Loss (kW)	210.98	111.03	70.862	68.17	67.868	87.166
Total Q Loss (kVAR)	143.02	81.682	56.762	55.044	54.828	59.773

Figure 2. Variation in Total Power Losses of IEEE 33 bus RDS with implementation of various DGs.

*Power Losses:*Figure 2. indicates the decrease in the total active and reactive power losses on implementing of various DGs with the total power loss saving of 99.95 kW, 140.12 kW, 142.81 kW, 143.12 kW when implementing single DG at Unity power factor (UPF), 0.9 pf lag, 0.85 pf lag, optimal value of 0.82378 pf lag respectively & 123.82 kW on the implementation of multiple DG at UPF. Table 2 represents the variation of parameters on DG allocation.

Table 2. Effect of various Type of DGs on IEEE 33 bus RDS.

Parameters	DG Allocation Size (Location) (kVA)	Total P_{loss} (kW)	Total Q_{loss} (kVAR)	%P_{loss} Reduction	% Q_{loss} Reduction	Min Voltage p.u (Bus)
Base Case	-	210.982	143.022	-	-	0.9038 (18)
SingleDG UPF	2590.252 (6)	111.03	81.682	47.37%	42.88%	0.9424 (18)
Single DG 0.9 lag	3073.499 (6)	70.862	57.762	66.41%	60.31%	0.9575 (18)
Single DG 0.85 lag	3103.022 (6)	68.169	55.044	67.69%	61.51%	0.9584 (18)
Single DG Optimal pf	3106.561 (6)	67.868	54.828	67.83%	61.67%	0.9584 (18)
Multi DG	851.525 (13) 1157.576 (30)	87.166	59.773	58.68%	58.31%	0.9685(33)

4.2 Effect on Voltage Profile & Power Losses of IEEE 69 bus RDS

In the instance of IEEE 69 bus RDS, the total load drawn from the substation is 3802.6 kW and 2694.6 kVAR. According to the load-flow study done using DLF on the test system without installing DG, the total active power loss amounts to 224.9887 kW while the total reactive power is 102.17 kVAR, with the minimum voltage being 0.90919 p.u at the bus no. 65.

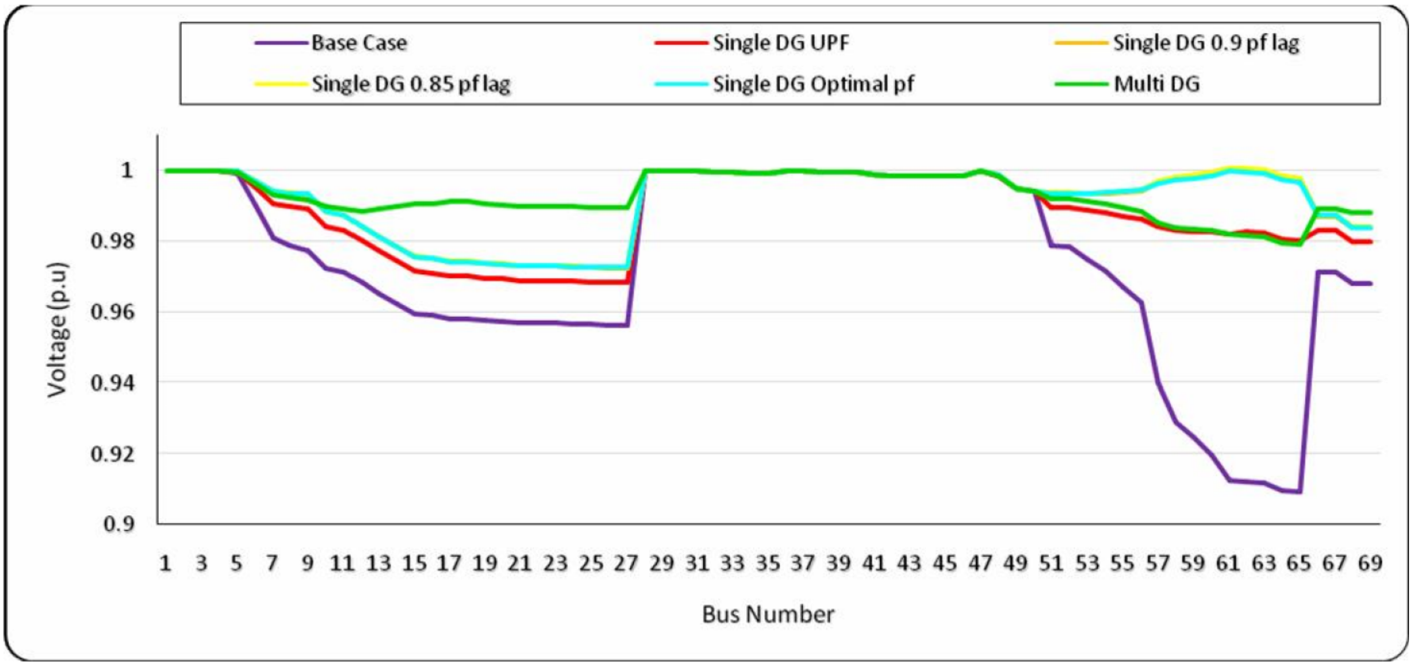


Figure 3. Variation in Voltage Profile of IEEE 69 bus RDS with implementation of various DGs.

Voltage Profile: Figure 3. represents the effect of the change in the number & power-factor of DG on the voltage profile, utilizing the aforementioned optimization approach and conducting the load flow analysis; the new voltage profile on the application of DG at the ideal position and the size determined shows the minimum value after DG implementation is more significant than the base case and keeps improving on increasing number of DGs and as the pf moves to its optimal value of 0.81496 pf lag.

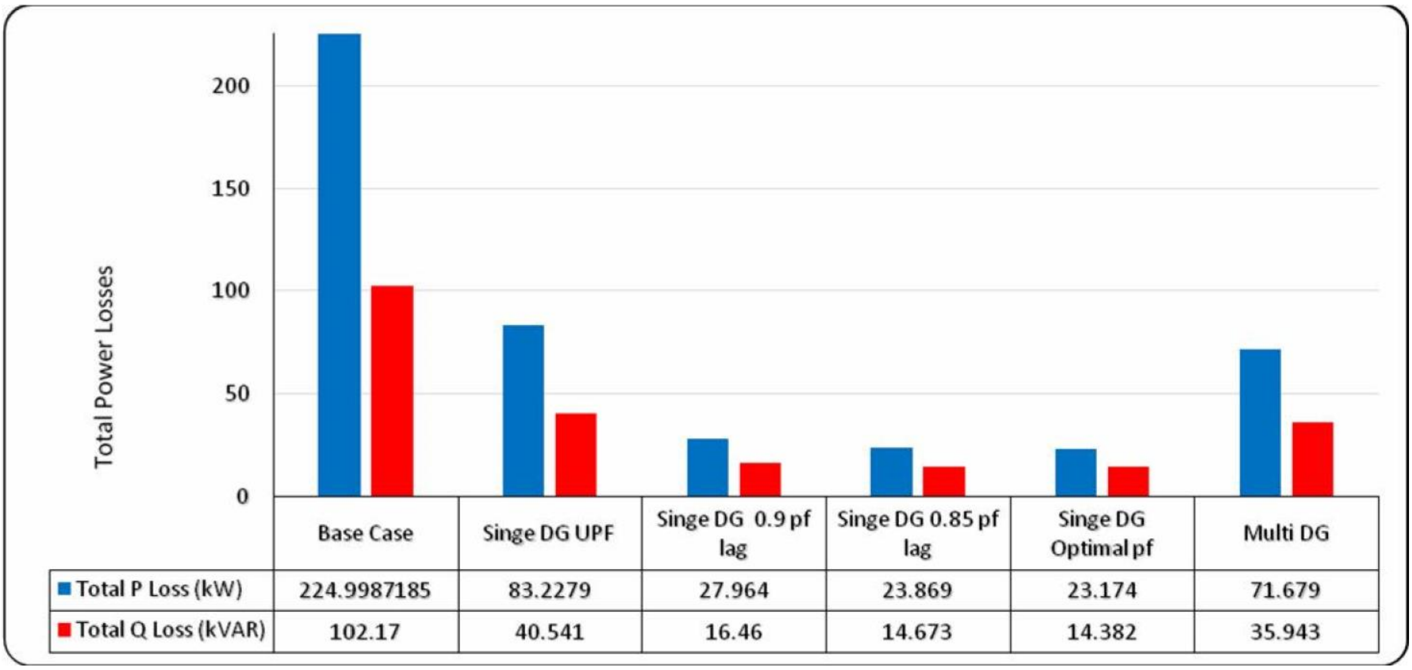


Figure 4. Variation in Total Power Losses of IEEE 69 bus RDS with implementation of various DGs.

Power Losses: Figure 4. indicates the decrease in the total active and reactive power losses on implementing of DGs with the total power loss saving being 141.77 kW, 197.03 kW, 201.13 kW, 201.824 kW when implementing single DG at UPF, 0.9 pf lag, 0.85 pf lag, and optimal value of 0.81496 pf lag & 153.32 kW when implementing multiple DG at UPF. Table 3 represents the variation of parameters on DG allocation.

Table 3. Effect of various Type of DGs on IEEE 69 bus RDS.

Parameters	DG Allocation Size (Location) (kVA)	Total P_{loss} (kW)	Total Q_{loss} (kVAR)	%P_{loss} Reduction	% Q_{loss} Reduction	Min Voltage p.u (Bus)
Base Case	-	224.998	102.166	-	-	0.9092 (65)
Single DG UPF	1872.823 (61)	83.228	40.541	63.01%	60.32%	0.9683 (27)
Single DG 0.9 lag	2217.441 (61)	27.964	16.46	87.57%	83.89%	0.9724 (27)
Single DG 0.85 lag	2240.445 (61)	23.869	14.673	89.29%	85.64%	0.9726 (27)
Single DG Optimal pf	2244.142 (61)	23.174	14.382	89.70%	85.92%	0.9725 (27)
Multi DG	531.523 (17) 1781.579 (61)	71.679	35.943	68.14%	64.82%	0.9789 (65)

4. Conclusions

In this paper power loss minimization is achieved with the deployment of DG by either increasing the number or tweaking the pf of DG thereby reducing the cost of energy along with significant improvements to the voltage profile. This enhances the system's efficiency, reliability and quality of power. The authors conclude that altering the pf from unity to the optimum value reduces power losses more prominently than increasing the number of DGs. On the other hand, increasing the number of DGs rather than altering the pf improves voltage profile significantly better. As a result, a trade-off must be made between the two DG variants, which can be extremely useful for deploying DGs in RDS according to the requirements. The authors find that the computation time for the GWO approach is significantly smaller than that of the PSO and GA techniques with equivalent accuracy. This approach may be used to realistic load models with DGs and FACTS controllers as well as practical systems that can save a significant amount of time and storage space.

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